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Abstract

This paper describes the MARS10 Monte Carlo code for inclusive simulation of three-dimensional hadronic and electromagnetic cascades and of muon transport in accelerator and detector components in the energy range from a few MeV up to 30 TeV. The specific features of the program are explained. The detailed description of general input and output with the corresponding comments and recomendations is given. The use of program for sophisticated sources, for complex compounds and for arbitrary geometries and magnetic fields as well as special versions of the program are described. Input and output examples are attached.

Contents

1 Introduction

MARS10 is a Monte Carlo program for inclusive simulation of three-dimensional hadronic and electromagnetic cascades in matter and of muon transport in radiation shielding, accelerator and detector components at energies up to 30 TeV. It allows fast cascade simulation with modest memory requirements, providing the availability of complex geometries with composite materials, presence of any magnetic fields, and a variety of scoring possibilities. There are a few problem-oriented versions.

Feynman's ideas concerning an inclusive approach to multiparticle reactions[1] and statistical weighting methods served as a basis for the original program MARS[2] and for developing in parallel CASIM[3]. To construct a cascade tree only a fixed number of particles from each vertex is chosen (four in MARS10) and in the simplest case each carries a statistical weight which is equal to the partial mean multiplicity of the particular event. Energy and momentum are conserved on the average over a number of collisions.

This paper describes briefly the basis of the inclusive approach, the main features of MARS10 code, general input and output, the use of the program for complex geometries and magnetic fields. Special versions of the MARS system are also described.

2 MARS10 Main Features

The practical reasons for the inclusive scheme as described in [4, 5] are:

- CPU time per incident particle grows only logarithmically with incident energy, compared to the linear rise in the exclusive mode, which allows the easier simulation of multi-TeV cascades;

- in many applications one considers effects due to the simultaneous interactions of a huge number of particles, so to describe the cascade it is sufficient to obtain the first moment of the distribution function using the inclusive cross-sections, in the same manner as with Boltzman's equation;

- experimental inclusive spectra are more readily available than exclusive ones;

- the use of statistical weights allows the production of a given particle type to be enhanced within the phase-space region of interest, especially for rarely produced particles.

In return for these features it comes the impossibility of directly studying fluctuations from cascade to cascade.

The mathematical foundation and the physical model of the MARS system are described in detail in [4, 6]. The program has been developed over many years. Besides the original version [2] the milestones were MARS3[7], MARS4[8], MARS6[9], MARS8[10], MARS9[11] and the first release of MARS10[12].

The specific features of the current MARS10 code[5] are:

- all the possible processes of interactions of hadron and leptons during their passage through matter are taken into account for the energy range from about 1 MeV to 30 TeV;

- simulation of hadron-nucleus interactions at $E \geq 5$ GeV is based on a set of the semi-theoretical formulas for a proton target, coupled with the additive quark model of hadron-nucleus interactions for fast secondaries and phenomenological model for slow particles [6, 13-16]; production of diffractive particles and nuclear de-excitation processes are modeled separately;

- at $E \leq 5$ GeV, the simulation of hadron-nucleus inelastic collisions is based on the formulas of Ref.[17];

- hadron inelastic cross-sections on different nuclei are calculated in the framework of the optical model and tabulated in the energy region from 10 MeV to 30 TeV for subsequent interpolation;

- special attention is paid to hadron processes with a small momentum transfer: elastic scattering, diffraction, multiple Coulomb scattering using Moliere's theory with allowance for nuclear size effects, δ-rays and direct e^+e^- production by hadrons [18, 19];

- arbitrary multi-medium geometry with optional superfine structure distributed, if desired, over hundreds of meters, and with arbitrary magnetic fields; an iteration-step method with precise localization of boundaries, which is especially refined near matter-vacuum edges [6, 20, 21];

- sixteen materials are built into the code (see Table 1) and others can be defined by the user; each material can be a mixture of up to 6 chemical elements; up to 10 different materials can simultaneously be involved in a specific calculation;

- quasi-analog simulation of electromagnetic showers, initiated by π^0 decays, by high energy $\delta-$rays and by prompt e^+e^- from hadrons, with the modified AEGIS program[22];

- transported particles: p, n, π, K, μ, e's, and γ's;

- initial particle energy: 10 MeV to 30 TeV;

- threshold energy: neutrons 10 MeV (0.025 eV in MARS11 version[23]), electrons and gammas 0.1 MeV, others 2 MeV [24];

- statistical fluctuation reduction options: bias techniques, exponential conversion of path length, and mathematical expectation; moreover, in MARS11 are added splitting, Russian roulette and synthesis with analytical solutions;

- scoring of three-dimensional distributions of star density, particle fluence and energy spectra, energy deposition density, temperature rise, dose equivalent, induced radioactivity and some integral numbers.

The particle code (jj, or $I0$ for incidents) is as follows:

1	p
2	n
3	π^+
4	π^-
5	K^+
6	K^-
7	μ^+
8	μ^-
9	γ
10	e^+
11	e^-

Kaons and muons are scored as separate particles only in the MARSMU version. In other versions of MARS they are included with the pion component.

Numerous comparisons of MARS calculational results with experimental data and with other codes predictions have been presented in [2, 4-13, 23, 24].

3 General Input

3.1 Defaults and Conventions

There are three levels of the input data definition in MARS10: defaults, input cards and user-supplied subroutines. All the input data have some default values (see Table 2), so if these are acceptable for the particular run their presence in the input sequence is not necessary. The shortest input is the only card: STOP.

User can re-define any of the default parameters with the card input sequence. This consists of option and data cards which allow the easy definition of rather complex cylindrically symetric (r-z-ϕ) geometries and sources. In the case of complex composite materials (instead of those in Table 1), of very complex objects, arbitrary sources and magnetic fields a few user-written subroutines should be provided (see section 5). For user convenience, arbitrarily complex geometry is usually built into one of the two "*standard*" geometries.

MARS10 uses the standard CERN FFREAD package to read FORMAT free data cards in the routine BEGIN. The structure of all the cards is the same:

KEYW a1 a2 ... ak N1= b1 b2 ... bm N2= c1 c2 ... cn,

where **KEYW** are the keywords assigned to the group of FORTRAN variables *a(i), b(i)* and *c(i)*; N1 and N2 are the addresses of the arrays *b(i)* and *c(i)*. The variables may be of the following types: integer, real, logical (represented by T or F) and alphanumerical (enclosed within ' '). Items are separated by blanks. The order of the input cards and their number are arbitrary. The only requirement is: the STOP card must be included and must be the last in the sequence. Example of the input sequence is given in the Appendix 1.

If for some reasons the use of the FFREAD package is impossible, the "*formated*" version of BEGIN reads in the data in the following formats:
A4 for keywords and material names AMA;
13A4 for a title MTEXT;
11L1 for logicals in IND(11);
I10 for all integer constants and
E10.0 for all real constants.

The card image input sequence is described in detail in the following subsection and cumulatively in Table 2.

The units in MARS10 are: energy in GeV, dimensions in cm, azimuthal angle ϕ in *degrees*, temperature rise ΔT in degrees Centigrade. The reference system is global Cartesian coordinate system (x, y, z). Any number of local coordinate systems can be placed in it with the help of subroutines REG1 and REG2. The z is longitudinal, and the positive direction is from left to right. The z axis is usually the center of symmetry, and as a rule the beam strikes along this axis in the positive direction. The positive direction of the x axis is up and the y axis is toward the viewer, completing a right-handed system.

3.2 Card Input Sequence

TITL MTEXT

Title of the problem, prints out a heading for the output. Default: TEST.

INDX IND(11)

Logical variables which control the options. Default: FFFFFFFFFFF.

$IND(1) = T$ - the program calculates and prints distributions of energy deposition density ϵ and related variables: dose equivalent, instantaneous temperature rise ΔT at given initial temperature $T_0 = TEMPO$ and number of particles per beam $N_0 = AINT$ (see VARS) and contact dose of induced radioactivity at N_0. Other values discussed in sect.4.3 are calculated independently of the $IND(1)$ meaning.

$IND(1) = F$ - does not calculate the energy deposition related values and runs the program about twice as fast.

$IND(2) = T$ - initiates "$Z -$ *sandwich standard*" geometry as a basis (see ZSEC and RSEC).

$IND(2) = F$ - initiates "$R -$ *sandwich standard*" geometry as a basis (see ZSEC and RSEC).

$IND(3) = T$ - initiates a calling of user-written subroutines BEG1, REG1 and REG2 to describe a complex particle source or presence of geometrical pieces, different from *standard* geometries.

$IND(3) = F$ - no *non-standard* inclusions in the studied system.

$IND(4) = T$ - indicates the presence of magnetic fields somewhere in the considered system, a user-written subroutine FIELD must be provided.

$IND(4) = F$ - no magnetic fields.

$IND(5) = T$ - indicates the tape reading/writing option (source reading, output writing, intermediate backups etc.).

$IND(5) = F$ - no external reading/writings.

$IND(6) = T$ - provides the use of mathematical expectation method: scoring of probabilities rather than direct (analog) particle contributions; very effective for "deep penetration" problem (thick shields etc.).

$IND(6) = F$ - "analog" scoring of transported particles.

$IND(7) = T$ - indicates that an incident particle interacts with probability EFF (see PART) with the point-like target placed in the system at coordinates (x_0, y_0, z_0) and starts with probability $(1 - EFF)$ from this point interacting with the rest of the system. By convention the material index for this target is equal to $IM = 1$.

$IND(7) = F$ - no point-like target.

$IND(8) = T$ - provides the maximum amount of output to be printed.

$IND(8) = F$ - correspondes to minimum output (see Sect.4).

$IND(9) = T$ - provides the use of special algorithms (as[19]) for construction of incident particles trajectories prior to the first inelastic nuclear interactions (edge scattering problem) and of Landau fluctuations simulation.

$IND(9) = F$ - does not use the above sophisticated algorithms, time saving.

$IND(10) = T$ - switches on MARSMU version for muon flux calculations.

$IND(10) = F$ - switches off MARSMU version, up to 5 times faster (per event).

$IND(11) = T$ - provides an azimuthal structure of scoring; adds the $\phi-$ dimension to the (r-z) geometries.

$IND(11) = F$ - no azimuthal division option.

NEVT NSTOP

Number of events (or incident particles) to be run. Default: 200.

ENRG E0, EM, PSTAM

$E0-$ incident particle kinetic energy. Default: 100.
$EM-$ hadron energy cutoff for flux and spectra scoring. Default: 0.01.
$PSTAM-$ star production threshold momentum. Default: 0.3 GeV/c (correspondes to 47 MeV for nucleons and 191 MeV for pions).

PART I0, EFF

$I0-$ incident particle type, $1 \leq I0 \leq 11$, but $I0$ can be equal to 5,6,7 or 8 only in MARSMU. Default: 1.
$EFF-$ point-like target efficiency; active if $IND(7) = T$. Default: 0.

BEAM IBEAM, SIXX, SIYY, SITX, SITY

$IBEAM-$ type of the incident beam, represents the beam profile:
0 - laterally infinitesimal beam;
1 - beam is distributed uniformly in the rectangular area with $SIXX$ and $SIYY$ half-sizes (along the corresponding axis);
2 - beam is Gaussian with R.M.S. equal to $\sigma_x = SIXX$ and $\sigma_y = SIYY$ in centimeters;
3 - beam is Gaussian as defined for $IBEAM = 2$ and additionally has an Gaussian angular spread with R.M.S. equal to $\sigma(\theta_x) = SITX$ and $\sigma(\theta_y) = SITY$ in radians.
$SIXX, SIYY, SITX, SITY-$ defined above, active if $IBEAM \geq 1$.
Default: 0 0 0 0 0.

INIT XINI, YINI, ZINI, DXIN, DYIN, DZIN

$XINI, YINI, ZINI-$ are initial x_0, y_0, z_0 coordinates of the beam spot center. Default: 0 0 0.
$DXIN, DYIN, DZIN-$ are initial direction cosines $\omega x_0, \omega y_0, \omega z_0$ of the beam. Default: 0 0 1.
User can provide his own arbitrary source in subroutine BEG1 (See section 5.2).

SMIN STEPEM, STEPH

$STEPEM-$ is an accuracy (in centimeters) of boundary localization in iterative transport algorithm, this is a second (in addition to $NSTOP$) controlling quantity for calculational accuracy to be good. Recomendation: $STEPEM \simeq 0.3 \times t_{min}$, where t_{min} is a smallest dimension of the smallest cell in the considered system. The larger $STEPEM$, the faster calculations. Default: 0.3
$STEPH-$ is some number which modestly controls the calculational time per event ($\simeq \log(STEPH/STEPEM)$) and calculational accuracy of construction of incident particle trajectory up to the first inelastic nuclear interaction for the case $IND(9) = F$. Recomendation: $STEPH = \min(\lambda, l)$ where λ is the mean inelastic length for hadrons and l is the length of the characteristic zone in the direction of predominant propagation of the particles. Default: 10.

VARS DEXP, RTIME, TEMPO, AINT

$DEXP-$ is an exponential conversion factor, which allows the increasing ($DEXP \geq 1$) or decreasing ($DEXP \leq 1$) of effective inelastic mean free path; usefull correspondingly for "deep penetration" problem and for compact restricted systems. Recomendation: $0.3 \leq DEXP \leq 3$. Default: 1.

$RTIME-$ is a period of an intermediate backups in *seconds*, active if $IND(5) = T$. Default: 0.

$TEMPO-$ is an initial temperature T_0 in $Kelvin$, defined in the region $4 \leq T_0 \leq 1800$. Default: 300.

$AINT-$ is a number of particles per beam N_0; necessary for calculations of a temperature rise (N_0 is assumed to be for single instantaneous spill) and crude estimation of a contact residiual dose (at the same time N_0 is assumed to be an average beam intensity in *protons per second*). Default: 10^{12}.

NMAT NR

$NR-$ is number of different materials to be included in the particular run. Materials can be single elements (built-in or defined by user) or complex compounds. Subroutine BEGIN calculates the effective atomic masses and numbers different for nuclear and electromagnetic processes. $1 \leq NR \leq 10$. Default: 1.

MATR AMA(10), ROW(10), ATW(10), ZAW(10)

This determines the NR specific materials and special index $IM = i$ is assigned to each material according to the input order. By definition $IM = 0$ correspondes to *vacuum* and $IM = NR + 1$ to outside of the system (*blackhole*) and user does not need to include them in the MATR. There are 16 other built in materials: LHE, BE, C, AL, LAR, TI, FE, CU, W, PB, U, AIR, CH, WATR, SOIL, CONC (See Table 1). If $AMA(i)$ coincides with one of these names, one does not need to define *ROW(i), ATW(i), ZAW(i)* for this i. If not, the user must define a material with its corresponding parameters as follows:

For single elements - arbitrary name $AMA(i)$, density $ROW(i)$ in g/cm^3, atomic mass $ATW(i)$ and atomic number $ZAW(i)$.

For each composite material - put in the MATR sequence the word 'MIXT' and density $ROW(i)$ and provide the corresponding definition of its composition in the subroutine MIXTUR (see sect.5.1), according to the input order. Default: FE.

NLNG LZ, NLZ

$LZ-$ is a number of longitudinal sections in the system for *standard* geometries. $1 \leq LZ \leq 50$. Default: 1.

$NLZ-$ multiplicates number of sections, described by ZSEC, it repeats these sections NLZ times, active only for $NLZ \geq 2$. Default: 1.

ZSEC ZSE(50), IZN(50), IZI(50), IZM(50)

$ZSE(i)-$ z-coordinate of the right boundary of $i-$ section. Default: 100.

$IZN(i)-$ number of subsections in $i-$ section. Default: 1.

$IZI(i)-$ material index IM of $i-$ section, active for $IND(2) = T$. Default: 1.

$IZM(i)-$ magnetic field index MA of $i-$ section, active for $IND(2) = T$ and $IND(4) = T$. Default: 0.

Let $MZ = NLZ \times LZ \times \sum NZ$. Then in the current version of MARS10 $MZ \leq 250$, but see additional restriction below. In the program by definition the smallest z-coordinate is $ZMIN$, most often $ZMIN = z_0 = 0$. The maximum longitudinal dimension of the system is $ZMAX-$ the largest z-coordinate.

NLTR LR

LR is a number of radial sections in the system for *standard* geometries. In the current version $LR \leq 10$. Default: 1.

RSEC RSE(10), IRN(10), IRI(10), IRM(10)

$RSE(i)-$ radius of $i-$ lateral section. Default: 5.

$IRN(i)-$ number of radial subsections in $i-$ lateral section. Default: 1.

$IRI(i)-$ material index IM of $i-$ lateral section, active for $IND(2) = F$. Default: 1.

$IRM(i)-$ magnetic field index MA of $i-$ lateral section, active for $IND(2) = F$ and $IND(4) = T$. Default: 0.

Let $MR = LR \times \sum NR$. Then in the current version $MR \leq 10$, but can be easily extended in subroutine REG1. For $IND(11) = F$ the overall restriction is $MZ \times MR \leq 500$. The maximum radial dimension of the system is $RMAX$.

NAZM NF

NF is a number of azimuthal bins, $1 \leq NF \leq 12$. To be presented in the input sequence only if $IND(11) = T$. Default: 1.
For $IND(11) = T$ the overall restriction is $MZ \times MR \times NF \leq 500$.

AZIM FIB(12)

The azimuthal grid, $0 \leq FIB(i) \leq 360$. To be presented in the input sequence only if $IND(11) = T$ and $NF \geq 2$. Default: 0.

NOBL NOB

NOB is a number of special regions in which particle energy spectra will be scored, $0 \leq NOB \leq 3$. Default: 0.

RZOB RZO(4,3)

Presented in the input sequence only if $NOB \geq 1$. Determines the sizes of $i-$ region for particle energy spectra scoring:
$RZO(1,i)-$ minimum radius $RMI(i)$, $0 \leq RMI \leq RMAX$.
Default: 0.
$RZO(2,i)-$ maximum radius $RMA(i)$, $RMI \leq RMA \leq RMAX$.
Default: 0.
$RZO(3,i)-$ left z-coordinate $ZMI(i)$, $ZMIN \leq ZMI \leq ZMAX$.
Default: 0.
$RZO(4,i)-$ right z-coordinate $ZMA(i)$, $ZMI \leq ZMA \leq ZMAX$.
Default: 0.

PLOT RPLOT, ZPLO1, ZPLO2, ZPLO3

Control plotting of the geometry cross-sections.
$RPLOT-$ maximum x or y coordinate to be presented in plots;
$ZPLO1-$ z-coordinate for the first cross-section of geometry;
$ZPLO2-$ z-coordinate for the second cross-section of geometry;
$ZPLO3-$ maximum z-coordinate of geometry to be printed.
If all these numbers are equal to zero there is no plotting.
Default: 0 0 0 0.

STOP Stops the input session
Any cards given after this are meaningless.

An example of the input sequence is presented in Appendix 1.

4 General Output

The output of MARS10 is essentially self-explainatory. It consists of three main sections: input status, geometrical regions enumeration and printout of Monte Carlo session results.

4.1 Input Status

Subroutine BEGIN prints the cards it has read and the calculated quantities to be used in the Monte Carlo session. Every value is provided with the corresponding keyword and title. The following is printed consecutively:

Title of the problem, options logical statement, requested number of incidents (events), incident kinetic energy, cutoff energy for hadron flux calculation, star production threshold, incident particle type, initial coordinates and direction cosines of the beam spot center, type of the incident beam, R.M.S. beam spot sizes and angular spread, accuracy of boundaries localization $STEPEM$ and control number $STEPH$, exponential conversion factor, period of intermidiate backups, initial temperature and beam intensity.

Then for each material the following values that have been read and calculated are printed: material index, material name, averaged atomic mass and atomic number, averaged electron density, ionization potential, critical energy and radiation length, contents of composite materials (if any), threshold energies for δ-electrons and direct e^+e^- pair production by charged hadrons, lengths for inelastic hadron-nuclear interactions at incident energy $E0$ and ionization ranges at the cutoff energy EM, some details of geometry.

If $IND(11) = T$ there is a printout of the azimuthal grid and if $NOB \geq 1-$ a printout of radial and longitudinal boundaries of macro-regions for particle spectra scoring.

If all of $RPLOT$, $ZPLO1$, $ZPLO2$, $ZPLO3$ are not equal to zero, two lateral and one longitudinal cross sectional views will be drawn.

4.2 Regions Enumeration

In this section, for the *standard* (r, z, ϕ) part of the considered geometry, the table is printed, which indicates a correspondence of regions boundaries and unique numbers N, assigned to each region. Also printed are corresponding material and magnetic field indexes. The calculational results of Section 4.3 are referenced to this table by a region number N.

4.3 Monte Carlo Results

This section contains the results of the Monte Carlo session as a number of tables and single quantities. All results are normalized to one incident particle (to one event), only temperature rise and residiual dose distributions are normalized to $AINT$ incidents (events). The following tables are printed here consecutively, if $IND(8) = T$:

1. Longitudinal integrated lateral distributions of
   a) charged and total star density and hadron flux and
   b) partial and total energy deposition.

2. Lateral integrated longitudinal distributions of partial and total energy deposition, corresponding cumulative distribution and total energy deposited via the different channels: low-energy particles from the nuclear de-excitation processes, electromagnetic showers and ionization losses of charged hadrons.

3. Three-dimensional star density distribution *(stars per cubic centimeter)* induced by charged hadrons, by all hadrons and the corresponding statistical error (one R.M.S.) for momenta $\geq PSTAM$. Collision estimator.

4. Three-dimensional hadron flux distributions *(particles per centimeter squared)* and the corresponding statistical errors for kinetic energy $\geq EM$. Track-length estimator.

5. Total number of stars produced in the system.

6. Lateral integrated longitudinal distributions of star density and hadron flux.

7. Three-dimensional distribution of energy deposition density brought by low-energy particles from de-excitation of nuclei, *(GeV/g)*.

8. Three-dimensional distribution of energy deposition density of electromagnetic showers produced by π^0 decays, by high energy $\delta-$rays and by prompt e^+e^- pairs from hadrons, *(GeV/g)*.

9. Three-dimensional distribution of energy deposition density from hadronic electromagnetic losses with limited energy transfer,*(GeV/g)*.

10. Three-dimensional distribution of total energy deposition density, *(GeV/g)*.

11. Three-dimensional distribution of dose equivalent, *(Rem)*.

12. Crude estimation of three-dimensional distribution of residual dose, *(Rad/hr)*, after 30 days irradiation at the mean beam intensity $AINT$ protons/sec and 1 day cooling. These values reflect the reality for more or less thick systems, beyond the lateral thickness of $\geq \lambda_{in}$.

13. Three-dimensional distribution of instantaneous temperature rise at given initial temperature $T_0 = TEMPO$ and number of particles per single beam pulse $N_0 = AINT$.

14. Longitudinal distribution of relative energy deposition by charged particles falling below the thresholds: 2 MeV for hadrons and 0.2 MeV for leptons. The two presented distributions are for the first smallest radial bin and for the rest of the system.

15. Leakage data: number and energy of albedo hadrons, of hadrons passed through the whole system and of hadrons that escaped the sides of the system; leakage energy of low-energy neutrons and of electromagnetic showers; total leakage energy; energy balance.

16. Leakage energy spectra of different particles for the upstream plane, downstream plane and for the rest of the system.

17. Three-dimensional distribution of the *relative* statistical errors of star densities, fluxes and energy deposition densities.

18. If $NOB \geq 1$, energy spectra of different particles in the pre-determined special regions.

If the user defines geometrically complex pieces (see sect.5.3) as a supplement to the *standard* geometries, additionally the program prints particle fluxes and energy deposition densities with corresponding statistical errors for each *non-standard* region.

If $IND(1) = F$, the tables No. **1b, 2, 7-14, 17** will be absent in the output.

If $IND(8) = F$, the tables No. **7, 8, 9, 11, 12, 14, 17** will be absent in the output.

If $IND(10) = T$, the only tables No. **4, 16** and **18** of the above sequence will be presented in the output, but last two contain muon spectra (instead hadron ones) and in addition tables of three-dimensional muon flux distribution and the corresponding statistical errors will be printed.

If IO = 9,10 or 11, i.e. incident particle is γ, e^- or e^+, the only tables No. **1b, 2, 10, 13** and **16** are currently presented in the standard output.

If there is an access to the graphics package TOPDRAWER, one can have the high resolution plots for most of the above distributions.

An example of the full output sequence is presented in Appendix 2.

5 User-supplied Subroutines

5.1 Compounds (MIXTUR)

To define complex composite materials not built into the current version of MARS10 (see Table 1) user must supply subroutine MIXTUR(I,M,A,Z,W). For each non-standard material marked in the input sequence with *'MIXT'* this subroutine has to define number of components in the compound M, atomic masses $A(M)$, atomic numbers $Z(M)$ and relative fractions of components $W(M)$ in the compound. Input material index I is determined according to the input order of material cards $MATR$. An example of the subroutine for the case when the first three materials are the single elements (from Table 1 or defined on the input card MATR), the fourth is polyethylene and the fifth is SiO_2 with 5% of water is presented below:

```
      SUBROUTINE MIXTUR(I,M,A,Z,W)
C DEFINES THE COMPOSITION OF THE COMPOUND
C INPUT: I - MATERIAL INDEX
C OUTPUT:
C M - NUMBER OF COMPONENTS IN MATERIAL 'I'
C A,Z - ATOMIC MASSES AND NUMBERS OF COMPONENTS
C W - RELATIVE FRACTIONS OF COMPONENTS
C 2.LE.M.LE.6
DIMENSION A(1),Z(1),W(1)
GO TO(1,1,1,4,5),I
C SI, FE, AL
1 RETURN
C CH2
4 M=2
A(1)=12.
A(2)=1.
Z(1)=6.
Z(2)=1.
W(1)=12./14.
W(2)=2./14.
RETURN
C SIO2 + 5 % H2O
5 M=3
A(1)=28.
A(2)=16.
A(3)=1.
Z(1)=14.
Z(2)=8.
Z(3)=1.
S=0.95*(28.+32.)+0.05*18.
W(1)=0.95*28./S
W(2)=(0.95*32+0.05*16.)/S
W(3)=0.05*2./S
RETURN
END
```

5.2 Source (BEG1)

The initial source of almost any complexity can be described in the subroutine BEG1(JJ,W,E,X,Y,Z,DX,DY,DZ), which is called when $IND(3) = T$. This is also useful for more efficient calculations in very extended cases: geometrically (e.g. beam loss problem in accelerators) or energetically (e.g. thermal neutron flux calculations), when the problem should be solved in a two (or more) consecutive steps. For example, the subroutine can look as follows:

```
*****************************************************
SUBROUTINE BEG1(JJ,W,E,X,Y,Z,DX,DY,DZ)
C
C RE-DEFINES EACH OR ANY OF THE 9 PARAMETERS
C OF INITIAL SOURCE PARTICLES
C
DATA R,PI/3.5,3.1415926/
A=2.*PI*RNDM(-1.)
X=R*SIN(A)
Y=R*COS(A)
Z=600.*RNDM(-1.)
RETURN
END
*****************************************************
```

In this subroutine the user may define any or all of the 9 output parameters in case he wants them to be different of ones defined in the input sequence for different events. The parameters are particle type (JJ), statistical weight of the current event (W, as a default W=1), kinetic energy of initial particle(E), initial coordinates(X,Y,Z) and initial direction cosines(DX,DY,DZ). Before each call of subroutine BEG1 (once per event) all 9 parameters are equal to input ones and any can be changed inside.

This option is useful when one needs to use a separate particle generator (say ISAJET) or pre-calculated extended source (say beam loss distribution). Any part of such an external source can be read in and for each call subroutine BEG1 must give a new set of output parameters.

5.3 Geometries (REG1, REG2)

If one wants to study cascades in a sophisticated geometry not embraced by the above options, two additional user-written subroutines must be provided with $IND(3) = T$. MARS10 allows user to place geometrical objects of almost any complexity inside the pre-defined *standard* (r-z-ϕ) geometry. By convention the total number of *standard* regions $NFZP$ must be $NFZP \geq 1$. With the help of his own subroutines REG1(X,Y,Z,N,NIM) and REG2(N,IM,MAG) the user can describe arbitrary physical regions with numbers from the interval $NFZP + 1 \leq N \leq NMAX$, where NMAX=500. Each region can be divided to any quantity of arbitrary subregions with unique numbers NIM from interval $0 \leq NIM \leq 10^6$. Default: NIM=0. This feature provides the possibility of distinguishing geometrical zones without scoring results there.

For each call, subroutine REG1(X,Y,Z,N,NIM) finds the position of the given point (X, Y, Z) in the system: it determines the corresponding physical region number N (each with its own material index) and, if one wishes, the subregion number NIM. The second subroutine REG2(N,IM,MAG) attributes to a given $N(\geq NFZP+1)$ the material index IM and if $IND(4) = T$, the magnetic index MAG. The last parameter is used in subroutine FIELD to determine the type of magnetic field (uniform, dipole, quadrupole etc.) in the region N. Default: $MAG = 0$ (no magnetic field in the region).

Simple examples of the subroutines are:

```
**************************************************
SUBROUTINE REG1(X,Y,Z,N,NIM)
C
C FINDS THE PLACE OF GIVEN POINT IN THE SYSTEM
C INPUT: X, Y, Z
C OUTPUT: N - PHYSICAL REGION NUMBER,
C NIM - GEOMETRICAL SUBREGION NUMBER
C
IF(Z.LT.300.) RETURN
R2=X*X+Y*Y
N=201
IF(R2.LE.12.25) RETURN
IF(ABS(X).GT.5.) GO TO 1
```

```
IF(ABS(Y).GT.7.) GO TO 1
N=202
RETURN
1 N=203
IF(R2.LT.225.) RETURN
N=0
RETURN
END
****************************************************
SUBROUTINE REG2(N,IM,MAG)
C
C FINDS THE MATERIAL AND MAGNETIC INDEXES
C INPUT: N - PHYSICAL REGION NUMBER
C OUTPUT: IM - MATERIAL INDEX,
C MAG - MAGNETIC FIELD INDEX
C
DATA IMU/0,2,1/
IM=IMU(N-200)
RETURN
END
****************************************************
```

By convention the region outside of the system has a number $N = 0$. The user must pay a special attention to careful programming of subroutines REG1 (especially) and REG2, because the geometrical modules consume about 80 % of the CPU time, as is typical of cascade Monte Carlo programs.

5.4 Magnetic Fields (FIELD)

If $IND(4) = T$ the user must provide subroutine FIELD to describe components of magnetic field (BX, BY, BZ) in the regions with $MAG \neq 0$. Parameter MAG defined in REG2 indicates the type of the field in the region and then one can use a corresponding map or analytical expression to find the meaning of the field in the point (X, Y, Z). The unit for magnetic field is $Tesla$.

An example of the subroutine is:

```
**************************************************
SUBROUTINE FIELD(X,Y,Z)
C
C FINDS COMPONENTS OF MAGNETIC FIELD
C INPUT: MAG - MAGNETIC INDEX AT THE GIVEN POINT (X,Y,Z)
C OUTPUT: BX, BY, BZ IN TESLA
C
COMMON/DEPMAG/I,MAG,BX,BY,BZ
BX=5.
BY=0.
BZ=0.
IF(MAG.EQ.2) BX=-5.
RETURN
END
**************************************************
```

6 Special Options

The use of MARS10 options described in the previous section gives a possibility of solving of variety of problems. Especially attractive turns out to be a multi-step approach. Three most successfull examples are:

- MARTUR package[20], designed for purposes of beam loss minimization in the superconducting accelerators. It carefully simulates the primary source (septa, scrapers and other *targets*), calculates the consequent beam loss distribution in the accelerator lattice using the modified TURTLE code[25] or other lattice particle tracking program and then simulates hadronic and electromagnetic cascades in places of interest. It is extensively used in the UNK project and has been used to find corrective measures which resulted in a five-fold increase of the beam intensity of the Tevatron during fast resonant extraction [26]. Recently the same approach was used to design an internal beam abort system for the Tevatron upgrade[27].

- New package [28, 29], which married MARS10, ISAJET[30] and GHEISHA[31], designed to optimize calorimeter energy resolutions and background conditions at collider detectors.

- MARS11 package[23], created to calculate low-energy neutrons distributions in high energy accelerators environment.

Another version of the MARS system which has been used quite extensively is MARSMU [32, 33], which permits calculations of muon distributions in detectors, global shields, muon shields at neutrino beams, etc.

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Table 1 : Built-in materials.

NAME	$\rho(g/cm^3)$	A	Z	Material
LHE	0.125	4.00	2	Liq. Helium
BE	1.85	9.01	4	Beryllium
C	1.71	12.01	6	Graphite
AL	2.70	26.98	13	Aluminium
LAR	1.40	39.95	18	Liq. Argon
TI	4.54	47.88	22	Titanium
FE	7.86	55.85	26	Iron
CU	8.92	63.54	29	Copper
W	19.3	183.85	74	Tungsten
PB	11.34	207.19	82	Lead
U	18.7	238.03	92	Uranium
AIR	0.00121			Air
CH	1.03			Polystyrene
WATR	1.00			Water
SOIL	1.90			Soil
CONC	2.35			Concrete

Table 2 : Optional MARS10 input variables and their defaults.

Keyword	Variables and Arrays	Default
TITL	MTEXT	TEST
INDX	IND(11)	FFFFFFFFFFF
NEVT	NSTOP	200
ENRG	E0, EM, PSTAM	100, 0.01, 0.3
PART	I0, EFF	1, 0.
BEAM	IBEAM, SIXX, SIYY, SITX, SITY	5*0
INIT	XINI, YINI, ZINI, DXIN, DYIN, DZIN	5*0., 1.
SMIN	STEPEM, STEPH	0.3, 10.
VARS	DEXP, RTIME, TEMPO, AINT	1, 0, 300, 10^{12}
NMAT	NR	1
MATR	AMA(10), ROW(10), ATW(10), ZAW(10)	FE, 39*0
NLNG	LZ, NLZ	1, 1
ZSEC	ZSE(50), IZN(50), IZI(50), IZM(50)	100.,49*0,1,49*0,1,99*0
NLTR	LR	1
RSEC	RSE(10), IRN(10), IRI(10), IRM(10)	5.,9*0,1,9*0,1,19*0
NAZM	NF	1
AZIM	FIB(12)	12*0.
NOBL	NOB	0
RZOB	RZO(4,3)	12*0.
PLOT	RPLOT, ZPLO1, ZPLO2, ZPLO3	4*0.
STOP		

APPENDIX 1. Input Example

```
TITL 'HYPOTHETIC BEAM ABSORBER IN A HOLE'
INDX T
NEVT 1000
ENRG 1500.
BEAM 2 0.025 0.063
INIT -3.
SMIN 0.2 20.
NMAT 5
MATR 'FE' 'AL' 'SI' 'MIXT' 'MIXT'
13=9.36 0.94 2.1 23=28.09 33=14.
NLNG 2
ZSEC 100. 400. 51=4 6
NLTR 7
RSEC 2. 8. 10. 11. 15. 40. 60.
12=3 17=2 21=0 1 2 3 4 0 5
STOP
```

APPENDIX 2. Output Example

The output shown below is the printout produced by the above input sequence coupled with the subroutine MIXTUR of the example of sect. 5.1. The program took 4.2 minutes of VAX-8650 to run 1000 incidents of 1500 GeV protons for this multi-media, multi-layer, 4-meter-long absorber with a hole and vacuum gap. Minimum output option is used. Statistical errors in regions of interest can be adjusted by changing number of events on the card NEVT.

```
TITL:          HYPOTHETIC BEAM ABSORBER IN A HOLE
INDX:          OPTIONS:   T F F F F F F F F F F
NEVT:          MAXIMUM NUMBER OF INCIDENTS:     1000
ENRG:          INCIDENT KINETIC ENERGY E0= 0.1500E+04 GEV
ENRG:          HADRONS ENERGY CUT OFF  EM=   0.010 GEV
ENRG:          STAR PRODUCTION THRESHOLD  PSTAM=   0.30 GEV/C,   ESTAM:   0.047   0.191
PART:          INCIDENT PARTICLE - P   CODE IO= 1
INIT:          INITIAL BEAM COORDINATES X,Y,Z (CM):-0.30000E+01 0.00000E+00 0.00000E+00
INIT:              AND DIRECTION COSINES DX,DY,DZ : 0.00000E+00 0.00000E+00 0.10000E+01
BEAM:          TYPE OF BEAM:  2      TARGET EFFICIENCY: 0.000E+00
BEAM:          SIX,SIY(CM)=  0.2500E-01 0.6300E-01   SITX,SITY=  0.0000E+00 0.0000E+00
SMIN:          STMIN(CM)= 0.2000E+00 ,   STEPH(CM)=  0.20E+02
VARS:          DEXP=  1.00,  RTIME(SEC)=     0.0,  TEMPO(K)=   300.0,  AINT=  0.100E+13
NMAT:          NR=  5

MATR:   MATERIAL INDEX IM= 1  CORRESPONDES TO FE    WITH DENSITY  7.8600 G/CM3
        ATOMIC MASS AND NUMBER:  NUCLEAR AVERAGED   55.85  26.00  ATOMIC AVERAGED   55.85  26.00
        MEAN:  ELECTRON DENSITY/6.013E23 =  0.4655      IONISATION POTENTIAL (EV) =  285.42
               CRITICAL ENERGY (GEV)     =  0.0247      RADIATION LENGTH (CM)     =    1.85
        PAIRS THRESHOLD FOR P AND PI (GEV) =    0.15E+04   0.22E+03
MATR:   MATERIAL INDEX IM= 2  CORRESPONDES TO AL    WITH DENSITY  2.7000 G/CM3
        ATOMIC MASS AND NUMBER:  NUCLEAR AVERAGED   26.98  13.00  ATOMIC AVERAGED   26.98  13.00
        MEAN:  ELECTRON DENSITY/6.013E23 =  0.4818      IONISATION POTENTIAL (EV) =  163.00
               CRITICAL ENERGY (GEV)     =  0.0475      RADIATION LENGTH (CM)     =    9.42
        PAIRS THRESHOLD FOR P AND PI (GEV) =    0.28E+04   0.41E+03
MATR:   MATERIAL INDEX IM= 3  CORRESPONDES TO SI    WITH DENSITY  9.3600 G/CM3
        ATOMIC MASS AND NUMBER:  NUCLEAR AVERAGED   28.09  14.00  ATOMIC AVERAGED   28.09  14.00
        MEAN:  ELECTRON DENSITY/6.013E23 =  0.4984      IONISATION POTENTIAL (EV) =  172.25
               CRITICAL ENERGY (GEV)     =  0.0443      RADIATION LENGTH (CM)     =    2.47
        PAIRS THRESHOLD FOR P AND PI (GEV) =    0.25E+04   0.37E+03
MATR:   MATERIAL INDEX IM= 4  CORRESPONDES TO MIXT  WITH DENSITY  0.9400 G/CM3
        ATOMIC MASS AND NUMBER:  NUCLEAR AVERAGED    8.96   4.62  ATOMIC AVERAGED    9.25   5.29
```

```
         MEAN:  ELECTRON DENSITY/6.Ø13E23 =  Ø.5714      IONISATION POTENTIAL (EV) =   54.58
                CRITICAL ENERGY (GEV)     =  Ø.1Ø46      RADIATION LENGTH (CM)     =   47.43

          2 ELEMENTS IN MIXTURE:

          Z         A     WEIGHT PART.

          6.ØØ     12.ØØ     Ø.857
          1.ØØ      1.ØØ     Ø.143

         PAIRS THRESHOLD FOR P AND PI (GEV) =    Ø.52E+Ø4   Ø.78E+Ø3

MATR:    MATERIAL INDEX IM= 5  CORRESPONDES TO MIXT  WITH DENSITY  2.1ØØØ G/CM3

         ATOMIC MASS AND NUMBER:  NUCLEAR AVERAGED   2Ø.88  1Ø.44  ATOMIC AVERAGED   21.45  1Ø.74

         MEAN:  ELECTRON DENSITY/6.Ø13E23 =  Ø.5ØØ9      IONISATION POTENTIAL (EV) =  126.55
                CRITICAL ENERGY (GEV)     =  Ø.0565      RADIATION LENGTH (CM)     =   13.68

          3 ELEMENTS IN MIXTURE:

          Z         A     WEIGHT PART.

         14.ØØ     28.ØØ     Ø.459
          8.ØØ     16.ØØ     Ø.539
          1.ØØ      1.ØØ     Ø.ØØ2

         PAIRS THRESHOLD FOR P AND PI (GEV) =    Ø.32E+Ø4   Ø.47E+Ø3
         KNOCK-ON ELECTRONS THRESHOLD AT DEL=  Ø.ØØ2 FOR P AND PI (GEV) =    Ø.69E+ØØ   Ø.1ØE+ØØ

         P, N, PI RANGES FOR NUCLEAR INTERACTION AT  Ø.15E+Ø4 GEV IN MATERIAL WITH

         INDEX 1         128.26    128.26    149.94 G/CM**2      Ø.163E+Ø2  Ø.163E+Ø2  Ø.191E+Ø2 CM

         INDEX 2         1Ø3.22    1Ø3.22    125.14 G/CM**2      Ø.382E+Ø2  Ø.382E+Ø2  Ø.463E+Ø2 CM

         INDEX 3         1Ø4.47    1Ø4.47    126.4Ø G/CM**2      Ø.112E+Ø2  Ø.112E+Ø2  Ø.135E+Ø2 CM

         INDEX 4          75.83     75.83     97.66 G/CM**2      Ø.8Ø7E+Ø2  Ø.8Ø7E+Ø2  Ø.1Ø4E+Ø3 CM

         INDEX 5          96.11     96.11    118.16 G/CM**2      Ø.458E+Ø2  Ø.458E+Ø2  Ø.563E+Ø2 CM

         P, N, PI IONIZATION RANGES AT Ø.95ØE-Ø2 GEV IN MATERIAL WITH

         INDEX 1           Ø.18      Ø.ØØ      Ø.76 G/CM**2      Ø.23ØE-Ø1  Ø.ØØØE+ØØ  Ø.972E-Ø1 CM

         INDEX 2           Ø.15      Ø.ØØ      Ø.67 G/CM**2      Ø.561E-Ø1  Ø.ØØØE+ØØ  Ø.248E+ØØ CM

         INDEX 3           Ø.15      Ø.ØØ      Ø.65 G/CM**2      Ø.159E-Ø1  Ø.ØØØE+ØØ  Ø.697E-Ø1 CM

         INDEX 4           Ø.1Ø      Ø.ØØ      Ø.48 G/CM**2      Ø.1Ø8E+ØØ  Ø.ØØØE+ØØ  Ø.5Ø7E+ØØ CM

         INDEX 5           Ø.14      Ø.ØØ      Ø.62 G/CM**2      Ø.654E-Ø1  Ø.ØØØE+ØØ  Ø.294E+ØØ CM

NLNG:              LZ =    2    NLZ=  1
NLTR:              LR =    7
NAZM:              NF =    1
NOBL:              NOB=    Ø

                   NPL-1=  1Ø   NZI= 1Ø   NFZP= 1ØØ

                   IEDEP= 1
```

NUMBER OF INCIDENTS 1000

THE LIST OF REGION NUMBERS AND THEIR CORRESPONDENCE TO STANDARD GEOMETRY SECTOR COORDINATES

RADIUS, CM
0.000E+00 0.200E+01 0.400E+01 0.600E+01 0.800E+01 0.100E+02 0.110E+02 0.150E+02 0.400E+02 0.500E+02 0.600E+02

Z, CM IM MAG										
0.000E+00										
	1	11	21	31	41	51	61	71	81	91
0.250E+02										
	2	12	22	32	42	52	62	72	82	92
0.500E+02										
	3	13	23	33	43	53	63	73	83	93
0.750E+02										
	4	14	24	34	44	54	64	74	84	94
0.100E+03										
	5	15	25	35	45	55	65	75	85	95
0.150E+03										
	6	16	26	36	46	56	66	76	86	96
0.200E+03										
	7	17	27	37	47	57	67	77	87	97
0.250E+03										
	8	18	28	38	48	58	68	78	88	98
0.300E+03										
	9	19	29	39	49	59	69	79	89	99
0.350E+03										
	10	20	30	40	50	60	70	80	90	100
0.400E+03										
IM=	0	1	1	1	2	3	4	0	5	5
MAG=	0	0	0	0	0	0	0	0	0	0

LONGITUDINAL INTEGRATED (0-ZMAX) VALUES

SCHAR, S/CM**3	0.00E+00	0.16E-01	0.54E-02	0.20E-02	0.93E-03	0.11E-02	0.89E-04	0.00E+00	0.33E-04	0.17E-04
STOT , S/CM**3	0.00E+00	0.26E-01	0.11E-01	0.69E-02	0.14E-02	0.25E-02	0.79E-03	0.00E+00	0.11E-03	0.88E-04
FLTOT, H/CM**2	0.38E+00	0.52E+00	0.21E+00	0.13E+00	0.76E-01	0.64E-01	0.43E-01	0.17E-01	0.10E-01	0.57E-02
EEX1 , GEV	0.00E+00	0.24E+02	0.14E+02	0.16E+02	0.27E+01	0.45E+01	0.26E+01	0.00E+00	0.65E+01	0.52E+01
EEMS , GEV	0.00E+00	0.82E+03	0.16E+03	0.61E+02	0.90E+01	0.14E+02	0.48E+01	0.00E+00	0.14E+02	0.11E+02
EDEX , GEV	0.00E+00	0.79E+02	0.44E+02	0.27E+02	0.74E+01	0.16E+02	0.54E+01	0.00E+00	0.19E+02	0.12E+02
ETOT , GEV	0.00E+00	0.93E+03	0.22E+03	0.10E+03	0.19E+02	0.33E+02	0.13E+02	0.00E+00	0.39E+02	0.29E+02

TOTAL ENERGY DEPOSITION, GEV

SCALE Z, CM	EX1	EMS	DEX	TOTAL IN SLAB	TOTAL IN BLOCK
0.000E+00					
	0.52E+01	0.15E+03	0.12E+02	0.170E+03	0.170E+03
0.250E+02					
	0.12E+02	0.40E+03	0.37E+02	0.443E+03	0.613E+03
0.500E+02					
	0.15E+02	0.28E+03	0.43E+02	0.340E+03	0.953E+03
0.750E+02					
	0.13E+02	0.14E+03	0.35E+02	0.185E+03	0.114E+04

0.100E+03					
	0.22E+02	0.11E+03	0.53E+02	0.181E+03	0.132E+04
0.150E+03					
	0.41E+01	0.23E+02	0.14E+02	0.407E+02	0.136E+04
0.200E+03					
	0.21E+01	0.58E+01	0.10E+02	0.182E+02	0.138E+04
0.250E+03					
	0.57E+00	0.15E+01	0.17E+01	0.382E+01	0.138E+04
0.300E+03					
	0.33E+00	0.10E+01	0.73E+00	0.206E+01	0.138E+04
0.350E+03					
	0.14E+00	0.34E+00	0.58E+00	0.106E+01	0.138E+04
SUM:	0.75E+02	0.11E+04	0.21E+03	0.138E+04	0.138E+04

STAR DENSITY, NO./CM**3 P.P.

REGION NUMBER		1	2	3	4	5	6	7	8	9	10
0	P+PI+K	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	TOTAL	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	+/-	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
10	P+PI+K	0.33E-01	0.75E-01	0.61E-01	0.34E-01	0.20E-01	0.55E-02	0.14E-02	0.10E-03	0.99E-04	0.28E-04
	TOTAL	0.45E-01	0.12E+00	0.12E+00	0.54E-01	0.32E-01	0.78E-02	0.17E-02	0.35E-03	0.16E-03	0.11E-03
	+/-	0.76E-02	0.17E-01	0.34E-01	0.86E-02	0.74E-02	0.22E-02	0.57E-03	0.24E-03	0.14E-03	0.80E-04
20	P+PI+K	0.46E-02	0.14E-01	0.31E-01	0.18E-01	0.71E-02	0.10E-02	0.49E-03	0.68E-04	0.47E-04	0.90E-05
	TOTAL	0.83E-02	0.28E-01	0.49E-01	0.43E-01	0.20E-01	0.42E-02	0.88E-03	0.23E-03	0.47E-04	0.90E-05
	+/-	0.20E-02	0.53E-02	0.14E-01	0.12E-01	0.64E-02	0.19E-02	0.39E-03	0.14E-03	0.41E-04	0.90E-05
30	P+PI+K	0.12E-02	0.45E-02	0.73E-02	0.64E-02	0.53E-02	0.42E-03	0.15E-03	0.49E-04	0.26E-05	0.18E-05
	TOTAL	0.19E-02	0.13E-01	0.20E-01	0.21E-01	0.25E-01	0.19E-02	0.18E-03	0.59E-04	0.26E-05	0.18E-05
	+/-	0.60E-03	0.37E-02	0.62E-02	0.75E-02	0.15E-01	0.65E-03	0.93E-04	0.24E-04	0.26E-05	0.18E-05
40	P+PI+K	0.19E-03	0.88E-03	0.23E-02	0.16E-02	0.48E-02	0.14E-03	0.24E-04	0.66E-06	0.35E-05	0.00E+00
	TOTAL	0.91E-03	0.17E-02	0.33E-02	0.37E-02	0.55E-02	0.49E-03	0.16E-03	0.91E-06	0.35E-05	0.28E-05
	+/-	0.34E-03	0.65E-03	0.78E-03	0.12E-02	0.43E-02	0.26E-03	0.12E-03	0.53E-06	0.34E-05	0.28E-05
50	P+PI+K	0.16E-03	0.25E-02	0.25E-02	0.23E-02	0.39E-02	0.66E-03	0.67E-04	0.93E-04	0.00E+00	0.12E-03
	TOTAL	0.34E-02	0.79E-02	0.59E-02	0.76E-02	0.52E-02	0.16E-02	0.27E-03	0.13E-03	0.25E-05	0.19E-03
	+/-	0.30E-02	0.22E-02	0.14E-02	0.22E-02	0.24E-02	0.60E-03	0.11E-03	0.82E-04	0.25E-05	0.14E-03
60	P+PI+K	0.22E-05	0.19E-03	0.17E-03	0.21E-03	0.26E-03	0.13E-03	0.15E-04	0.22E-05	0.99E-05	0.00E+00
	TOTAL	0.94E-04	0.15E-02	0.44E-03	0.71E-02	0.11E-02	0.27E-03	0.40E-03	0.40E-04	0.99E-05	0.00E+00
	+/-	0.55E-04	0.72E-03	0.14E-03	0.65E-02	0.32E-03	0.24E-03	0.33E-03	0.38E-04	0.99E-05	0.00E+00
70	P+PI+K	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	TOTAL	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	+/-	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
80	P+PI+K	0.37E-05	0.13E-04	0.16E-04	0.37E-04	0.58E-04	0.82E-04	0.34E-04	0.29E-04	0.22E-04	0.40E-05
	TOTAL	0.83E-05	0.50E-04	0.80E-04	0.18E-03	0.26E-03	0.20E-03	0.17E-03	0.77E-04	0.38E-04	0.81E-05
	+/-	0.42E-05	0.18E-04	0.28E-04	0.41E-04	0.98E-04	0.45E-04	0.63E-04	0.26E-04	0.20E-04	0.36E-05
90	P+PI+K	0.25E-07	0.23E-06	0.58E-05	0.49E-04	0.15E-04	0.30E-04	0.40E-04	0.14E-04	0.22E-05	0.23E-05
	TOTAL	0.26E-05	0.36E-04	0.25E-03	0.29E-03	0.10E-03	0.11E-03	0.14E-03	0.44E-04	0.14E-04	0.10E-04
	+/-	0.24E-05	0.17E-04	0.17E-03	0.15E-03	0.44E-04	0.41E-04	0.69E-04	0.20E-04	0.68E-05	0.42E-05

RANGE FLUENCE ESTIMATION, HADRONS/CM2

REGION NUMBER		1	2	3	4	5	6	7	8	9	10
					E.GE.	Ø.Ø1Ø GEV					
Ø		Ø.24E+ØØ	Ø.13E+Ø1	Ø.14E+Ø1	Ø.11E+Ø1	Ø.71E+ØØ	Ø.27E+ØØ	Ø.35E-Ø1	Ø.11E-Ø1	Ø.59E-Ø2	Ø.21E-Ø2
	+/-	Ø.36E-Ø1	Ø.26E+ØØ	Ø.21E+ØØ	Ø.23E+ØØ	Ø.26E+ØØ	Ø.11E+ØØ	Ø.1ØE-Ø1	Ø.44E-Ø2	Ø.28E-Ø2	Ø.15E-Ø2
1Ø		Ø.1ØE+Ø1	Ø.19E+Ø1	Ø.2ØE+Ø1	Ø.14E+Ø1	Ø.74E+ØØ	Ø.19E+ØØ	Ø.36E-Ø1	Ø.53E-Ø2	Ø.17E-Ø2	Ø.15E-Ø2
	+/-	Ø.14E+ØØ	Ø.15E+ØØ	Ø.19E+ØØ	Ø.15E+ØØ	Ø.16E+ØØ	Ø.45E-Ø1	Ø.13E-Ø1	Ø.24E-Ø2	Ø.99E-Ø3	Ø.89E-Ø3
2Ø		Ø.17E+ØØ	Ø.64E+ØØ	Ø.11E+Ø1	Ø.67E+ØØ	Ø.31E+ØØ	Ø.71E-Ø1	Ø.29E-Ø1	Ø.28E-Ø2	Ø.53E-Ø3	Ø.46E-Ø3
	+/-	Ø.22E-Ø1	Ø.72E-Ø1	Ø.22E+ØØ	Ø.86E-Ø1	Ø.63E-Ø1	Ø.19E-Ø1	Ø.12E-Ø1	Ø.12E-Ø2	Ø.37E-Ø3	Ø.37E-Ø3
3Ø		Ø.96E-Ø1	Ø.29E+ØØ	Ø.87E+ØØ	Ø.35E+ØØ	Ø.2ØE+ØØ	Ø.45E-Ø1	Ø.17E-Ø1	Ø.53E-Ø2	Ø.58E-Ø3	Ø.27E-Ø3
	+/-	Ø.18E-Ø1	Ø.33E-Ø1	Ø.27E+ØØ	Ø.6ØE-Ø1	Ø.4ØE-Ø1	Ø.1ØE-Ø1	Ø.68E-Ø2	Ø.23E-Ø2	Ø.36E-Ø3	Ø.21E-Ø3
4Ø		Ø.46E-Ø1	Ø.18E+ØØ	Ø.22E+ØØ	Ø.3ØE+ØØ	Ø.19E+ØØ	Ø.3ØE-Ø1	Ø.13E-Ø1	Ø.43E-Ø2	Ø.51E-Ø3	Ø.19E-Ø3
	+/-	Ø.78E-Ø2	Ø.23E-Ø1	Ø.31E-Ø1	Ø.73E-Ø1	Ø.6ØE-Ø1	Ø.66E-Ø2	Ø.71E-Ø2	Ø.19E-Ø2	Ø.3ØE-Ø3	Ø.15E-Ø3
5Ø		Ø.42E-Ø1	Ø.13E+ØØ	Ø.18E+ØØ	Ø.25E+ØØ	Ø.16E+ØØ	Ø.34E-Ø1	Ø.12E-Ø1	Ø.33E-Ø2	Ø.22E-Ø3	Ø.58E-Ø2
	+/-	Ø.16E-Ø1	Ø.17E-Ø1	Ø.27E-Ø1	Ø.64E-Ø1	Ø.56E-Ø1	Ø.94E-Ø2	Ø.6ØE-Ø2	Ø.15E-Ø2	Ø.16E-Ø3	Ø.56E-Ø2
6Ø		Ø.17E-Ø1	Ø.73E-Ø1	Ø.13E+ØØ	Ø.21E+ØØ	Ø.89E-Ø1	Ø.26E-Ø1	Ø.6ØE-Ø2	Ø.3ØE-Ø2	Ø.19E-Ø3	Ø.37E-Ø2
	+/-	Ø.36E-Ø2	Ø.98E-Ø2	Ø.21E-Ø1	Ø.87E-Ø1	Ø.21E-Ø1	Ø.61E-Ø2	Ø.16E-Ø2	Ø.12E-Ø2	Ø.13E-Ø3	Ø.36E-Ø2
7Ø		Ø.69E-Ø2	Ø.22E-Ø1	Ø.51E-Ø1	Ø.47E-Ø1	Ø.41E-Ø1	Ø.18E-Ø1	Ø.73E-Ø2	Ø.3ØE-Ø2	Ø.15E-Ø2	Ø.23E-Ø2
	+/-	Ø.18E-Ø2	Ø.38E-Ø2	Ø.1ØE-Ø1	Ø.12E-Ø1	Ø.8ØE-Ø2	Ø.4ØE-Ø2	Ø.13E-Ø2	Ø.71E-Ø3	Ø.43E-Ø3	Ø.14E-Ø2
8Ø		Ø.53E-Ø2	Ø.11E-Ø1	Ø.22E-Ø1	Ø.17E-Ø1	Ø.2ØE-Ø1	Ø.11E-Ø1	Ø.11E-Ø1	Ø.27E-Ø2	Ø.55E-Ø2	Ø.18E-Ø2
	+/-	Ø.17E-Ø2	Ø.23E-Ø2	Ø.55E-Ø2	Ø.32E-Ø2	Ø.44E-Ø2	Ø.17E-Ø2	Ø.29E-Ø2	Ø.63E-Ø3	Ø.29E-Ø2	Ø.99E-Ø3
9Ø		Ø.38E-Ø2	Ø.55E-Ø2	Ø.1ØE-Ø1	Ø.87E-Ø2	Ø.11E-Ø1	Ø.73E-Ø2	Ø.78E-Ø2	Ø.27E-Ø2	Ø.17E-Ø2	Ø.89E-Ø3
	+/-	Ø.14E-Ø2	Ø.12E-Ø2	Ø.35E-Ø2	Ø.14E-Ø2	Ø.29E-Ø2	Ø.23E-Ø2	Ø.22E-Ø2	Ø.82E-Ø3	Ø.9ØE-Ø3	Ø.38E-Ø3

TOTAL STARS NUMBER Ø.14ØE+Ø4

TOTAL LATERAL INTEGRATED STAR DENSITY AND FLUX FOR ZSCALE:

Z,CM	STARS/CM	FLUX
Ø.ØØE+ØØ		
	Ø.28E+Ø1	Ø.13E+Ø3
Ø.25E+Ø2		
	Ø.88E+Ø1	Ø.35E+Ø3
Ø.5ØE+Ø2		
	Ø.11E+Ø2	Ø.64E+Ø3
Ø.75E+Ø2		
	Ø.11E+Ø2	Ø.54E+Ø3
Ø.1ØE+Ø3		
	Ø.7ØE+Ø1	Ø.41E+Ø3
Ø.15E+Ø3		
	Ø.19E+Ø1	Ø.17E+Ø3
Ø.2ØE+Ø3		
	Ø.13E+Ø1	Ø.98E+Ø2
Ø.25E+Ø3		
	Ø.42E+ØØ	Ø.33E+Ø2
Ø.3ØE+Ø3		
	Ø.17E+ØØ	Ø.28E+Ø2
Ø.35E+Ø3		
	Ø.76E-Ø1	Ø.2ØE+Ø2

TOTAL ENERGY DEPOSITION, GEV/G P.P.

REGION NUMBER		1	2	3	4	5	6	7	8	9	10
0		0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	+/-	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
10		0.20E-01	0.47E-01	0.31E-01	0.15E-01	0.56E-02	0.95E-03	0.21E-03	0.26E-04	0.11E-04	0.37E-05
	+/-	0.17E-02	0.25E-02	0.21E-02	0.13E-02	0.79E-03	0.19E-03	0.74E-04	0.15E-04	0.98E-05	0.20E-05
20		0.12E-02	0.49E-02	0.54E-02	0.30E-02	0.14E-02	0.24E-03	0.90E-04	0.12E-04	0.36E-05	0.64E-06
	+/-	0.17E-03	0.43E-03	0.63E-03	0.36E-03	0.23E-03	0.66E-04	0.42E-04	0.51E-05	0.22E-05	0.53E-06
30		0.32E-03	0.12E-02	0.16E-02	0.12E-02	0.65E-03	0.12E-03	0.23E-04	0.66E-05	0.32E-05	0.99E-07
	+/-	0.67E-04	0.13E-03	0.25E-03	0.21E-03	0.21E-03	0.34E-04	0.11E-04	0.32E-05	0.20E-05	0.51E-07
40		0.10E-03	0.50E-03	0.57E-03	0.47E-03	0.35E-03	0.58E-04	0.25E-04	0.66E-05	0.96E-06	0.18E-06
	+/-	0.18E-04	0.73E-04	0.94E-04	0.89E-04	0.14E-03	0.14E-04	0.11E-04	0.29E-05	0.74E-06	0.11E-06
50		0.79E-04	0.32E-03	0.43E-03	0.35E-03	0.40E-03	0.42E-04	0.21E-04	0.39E-05	0.12E-05	0.24E-05
	+/-	0.19E-04	0.47E-04	0.80E-04	0.61E-04	0.21E-03	0.10E-04	0.12E-04	0.19E-05	0.73E-06	0.20E-05
60		0.88E-04	0.43E-03	0.23E-03	0.34E-03	0.22E-03	0.38E-04	0.28E-04	0.39E-05	0.85E-06	0.48E-06
	+/-	0.39E-04	0.10E-03	0.42E-04	0.89E-04	0.87E-04	0.10E-04	0.13E-04	0.18E-05	0.51E-06	0.25E-06
70		0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	+/-	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
80		0.73E-05	0.17E-04	0.23E-04	0.30E-04	0.47E-04	0.21E-04	0.14E-04	0.49E-05	0.37E-05	0.24E-05
	+/-	0.35E-05	0.33E-05	0.37E-05	0.48E-05	0.14E-04	0.35E-05	0.39E-05	0.15E-05	0.12E-05	0.11E-05
90		0.26E-05	0.74E-05	0.14E-04	0.17E-04	0.15E-04	0.21E-04	0.18E-04	0.33E-05	0.15E-05	0.51E-06
	+/-	0.86E-06	0.21E-05	0.29E-05	0.42E-05	0.34E-05	0.48E-05	0.73E-05	0.79E-06	0.47E-06	0.17E-06

HEATING, DEGR. AT T0= 0.300E+03 AINT= 0.100E+13

REGION NUMBER	1	2	3	4	5	6	7	8	9	10
0	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
10	0.70E+01	0.17E+02	0.11E+02	0.52E+01	0.20E+01	0.34E+00	0.75E-01	0.93E-02	0.39E-02	0.13E-02
20	0.44E+00	0.17E+01	0.19E+01	0.11E+01	0.51E+00	0.87E-01	0.32E-01	0.43E-02	0.13E-02	0.24E-03
30	0.12E+00	0.43E+00	0.59E+00	0.44E+00	0.23E+00	0.43E-01	0.84E-02	0.24E-02	0.12E-02	0.61E-04
40	0.18E-01	0.89E-01	0.10E+00	0.85E-01	0.62E-01	0.10E-01	0.44E-02	0.11E-02	0.12E-03	0.00E+00
50	0.15E-01	0.60E-01	0.81E-01	0.65E-01	0.75E-01	0.79E-02	0.40E-02	0.73E-03	0.12E-03	0.37E-03
60	0.79E-02	0.39E-01	0.21E-01	0.31E-01	0.20E-01	0.34E-02	0.26E-02	0.37E-03	0.92E-04	0.31E-04
70	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
80	0.98E-03	0.23E-02	0.31E-02	0.42E-02	0.66E-02	0.28E-02	0.20E-02	0.61E-03	0.49E-03	0.37E-03
90	0.37E-03	0.98E-03	0.20E-02	0.23E-02	0.21E-02	0.28E-02	0.23E-02	0.37E-03	0.12E-03	0.00E+00

LEAKAGE:	BACKWARD	FORWARD	SIDE
HADRONS LEAKAGE ENERGY, GEV:	Ø.6699E+ØØ	Ø.5026E+Ø1	Ø.5529E+Ø2
NUMBER OF LEAKAGE PARTICLES:	Ø.1Ø93E+Ø2	Ø.12Ø4E+Ø2	Ø.4574E+Ø3

LOW-ENERGY NEUTRONS LEAKAGE ENERGY, GEV: Ø.986E+Ø1
PHOTON AND ELECTRON LEAKAGE ENERGY, GEV: Ø.244E+Ø2
TOTAL LEAKAGE ENERGY, GEV: Ø.953E+Ø2

ENERGY BALANCE: ETOT= Ø.148ØE+Ø4 GEV, ETOT/EO= Ø.98672

LEAKAGE SPECTRA OF PARTICLES: PARTICLES/GEV

ENERGY SCALE, GEV	UPSTREAM PLANE			DOWNSTREAM PLANE			THE EXTERNAL CYLINDER		
	P	N	PI+/-	P	N	PI+/-	P	N	PI+/-
Ø.1ØØE-Ø1	Ø.15E+ØØ	Ø.13E+Ø3	Ø.ØØE+ØØ	Ø.ØØE+ØØ	Ø.11E+Ø1	Ø.ØØE+ØØ	Ø.11E+Ø1	Ø.51E+Ø4	Ø.64E+Ø1
Ø.2Ø2E-Ø1	Ø.ØØE+ØØ	Ø.12E+Ø3	Ø.31E+ØØ	Ø.ØØE+ØØ	Ø.31E+Ø1	Ø.46E+ØØ	Ø.83E+Ø1	Ø.23E+Ø4	Ø.19E+Ø2
Ø.4Ø6E-Ø1	Ø.58E-Ø1	Ø.86E+Ø2	Ø.15E+Ø2	Ø.71E+ØØ	Ø.7ØE+Ø2	Ø.24E+Ø1	Ø.32E+Ø2	Ø.35E+Ø4	Ø.13E+Ø3
Ø.819E-Ø1	Ø.73E-Ø3	Ø.29E+Ø2	Ø.41E+Ø1	Ø.ØØE+ØØ	Ø.15E+Ø2	Ø.16E+Ø1	Ø.16E+Ø3	Ø.87E+Ø3	Ø.12E+Ø3
Ø.165E+ØØ	Ø.ØØE+ØØ	Ø.59E+ØØ	Ø.12E+Ø1	Ø.53E-Ø3	Ø.37E+Ø2	Ø.27E-Ø2	Ø.36E+Ø2	Ø.39E+Ø3	Ø.37E+Ø2
Ø.333E+ØØ	Ø.ØØE+ØØ	Ø.ØØE+ØØ	Ø.16E-Ø4	Ø.18E-Ø1	Ø.55E+ØØ	Ø.56E-Ø1	Ø.98E+Ø1	Ø.32E+Ø2	Ø.25E+Ø2
Ø.671E+ØØ	Ø.ØØE+ØØ	Ø.ØØE+ØØ	Ø.ØØE+ØØ	Ø.26E-Ø1	Ø.42E-Ø1	Ø.61E+ØØ	Ø.58E+ØØ	Ø.29E+Ø1	Ø.69E+Ø1
Ø.135E+Ø1	Ø.ØØE+ØØ	Ø.ØØE+ØØ	Ø.ØØE+ØØ	Ø.1ØE+ØØ	Ø.49E-Ø1	Ø.17E+ØØ	Ø.89E-Ø1	Ø.18E+ØØ	Ø.75E-Ø1
Ø.273E+Ø1	Ø.ØØE+ØØ	Ø.ØØE+ØØ	Ø.ØØE+ØØ	Ø.14E-Ø5	Ø.77E-Ø3	Ø.67E-Ø1	Ø.18E-Ø1	Ø.31E-Ø3	Ø.43E-Ø1
Ø.55ØE+Ø1	Ø.ØØE+ØØ	Ø.ØØE+ØØ	Ø.ØØE+ØØ	Ø.ØØE+ØØ	Ø.ØØE+ØØ	Ø.19E-Ø1	Ø.ØØE+ØØ	Ø.ØØE+ØØ	Ø.28E-Ø2
Ø.111E+Ø2	Ø.ØØE+ØØ	Ø.ØØE+ØØ	Ø.ØØE+ØØ	Ø.ØØE+ØØ	Ø.ØØE+ØØ	Ø.ØØE+ØØ	Ø.ØØE+ØØ	Ø.ØØE+ØØ	Ø.ØØE+ØØ
Ø.223E+Ø2	Ø.ØØE+ØØ	Ø.ØØE+ØØ	Ø.ØØE+ØØ	Ø.ØØE+ØØ	Ø.ØØE+ØØ	Ø.ØØE+ØØ	Ø.ØØE+ØØ	Ø.ØØE+ØØ	Ø.ØØE+ØØ
Ø.451E+Ø2	Ø.ØØE+ØØ	Ø.ØØE+ØØ	Ø.ØØE+ØØ	Ø.ØØE+ØØ	Ø.ØØE+ØØ	Ø.ØØE+ØØ	Ø.ØØE+ØØ	Ø.ØØE+ØØ	Ø.ØØE+ØØ
Ø.9Ø8E+Ø2	Ø.ØØE+ØØ	Ø.ØØE+ØØ	Ø.ØØE+ØØ	Ø.ØØE+ØØ	Ø.ØØE+ØØ	Ø.ØØE+ØØ	Ø.ØØE+ØØ	Ø.ØØE+ØØ	Ø.ØØE+ØØ
Ø.183E+Ø3	Ø.ØØE+ØØ	Ø.ØØE+ØØ	Ø.ØØE+ØØ	Ø.ØØE+ØØ	Ø.ØØE+ØØ	Ø.ØØE+ØØ	Ø.ØØE+ØØ	Ø.ØØE+ØØ	Ø.ØØE+ØØ
Ø.369E+Ø3	Ø.ØØE+ØØ	Ø.ØØE+ØØ	Ø.ØØE+ØØ	Ø.ØØE+ØØ	Ø.ØØE+ØØ	Ø.ØØE+ØØ	Ø.ØØE+ØØ	Ø.ØØE+ØØ	Ø.ØØE+ØØ
Ø.744E+Ø3	Ø.ØØE+ØØ	Ø.ØØE+ØØ	Ø.ØØE+ØØ	Ø.ØØE+ØØ	Ø.ØØE+ØØ	Ø.ØØE+ØØ	Ø.ØØE+ØØ	Ø.ØØE+ØØ	Ø.ØØE+ØØ
Ø.933E+Ø3	Ø.ØØE+ØØ	Ø.ØØE+ØØ	Ø.ØØE+ØØ	Ø.ØØE+ØØ	Ø.ØØE+ØØ	Ø.ØØE+ØØ	Ø.ØØE+ØØ	Ø.ØØE+ØØ	Ø.ØØE+ØØ
Ø.112E+Ø4	Ø.ØØE+ØØ	Ø.ØØE+ØØ	Ø.ØØE+ØØ	Ø.ØØE+ØØ	Ø.ØØE+ØØ	Ø.ØØE+ØØ	Ø.ØØE+ØØ	Ø.ØØE+ØØ	Ø.ØØE+ØØ
Ø.131E+Ø4	Ø.ØØE+ØØ	Ø.ØØE+ØØ	Ø.ØØE+ØØ	Ø.ØØE+ØØ	Ø.ØØE+ØØ	Ø.ØØE+ØØ	Ø.ØØE+ØØ	Ø.ØØE+ØØ	Ø.ØØE+ØØ
Ø.15ØE+Ø4									
SUM, PARTICLES	Ø.39E-Ø2	Ø.98E+Ø1	Ø.12E+Ø1	Ø.19E+ØØ	Ø.11E+Ø2	Ø.12E+Ø1	Ø.25E+Ø2	Ø.4ØE+Ø3	Ø.36E+Ø2